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The prospects of energy forestry and agro-residues in the Lithuania's domestic energy supply

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ABSTRACT

Recent restructuring of the European agricultural sector should reduce the volume of traditional agricultural production dramatically and withdraw huge areas of arable land from turnover. As a result there is a great potential in breeding short rotation forestry (SRF) and short rotation coppice (SRC) plantations in uncultivated land of good agrarian condition. Lithuania (LIT) has a great potential for expanding local biofuel market and reap the derivative effects in relation to energy and environment on faster growing biomass like SRF, SRC and straw. Energy forestry and agro-residues lessen the environmental impact connected to energy production and consumption and contribute to meeting Lithuania's international obligations for the discharge of greenhouse gasses (CO_2, CH_4, N_2O), sustainability and biodiversity. This review contains practical information on the experience acquired by establishing SRF plantations in LIT as well as utilisation of energy forestry and agro-residues for heat and power. The paper details cultivation and harvesting of SRF, rationality of production, types and applications of industrial combustion systems. It was carefully compiled on the basis of available literature sources, national information and experiences and suggestions from local farmers. Other important issues, including support and incentive mechanisms as well as examples of successful implementation, are also discussed.

Contents

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1. Introduction

Recent restructuring of the European agricultural sector should reduce the volume of traditional agricultural production dramatically and withdraw huge areas of arable land from turnover. As a result there is a great potential in breeding short rotation forestry (SRF) and short rotation coppice (SRC) plantations in uncultivated land of good agrarian condition [1–11]. Forestry plantations in Europe are related with the creation of new working places in rural locations, increase of economic efficiency in abandoned land areas and sustaining arable land and people in rural territories. In comparison with annual agricultural crops SRF plantations are less labour consuming; however, they are more labour consuming compared with the agricultural land used extensively [12]. Though, such plantations can even reduce the number of working places in the regions with highly developed agricultural activities. SRF plantations should help improving the unemployment situation in rural areas at least during wintertime. The development of energy plantations is of exceptional importance in global aspect—fighting against the dangers of climate warming, acid precipitation, preservation of natural resources and contributing to the international goals of overall sustainable development.

There is a well-established attitude than farmers tend to switch from traditional farming to tree growing on their land, if they are able to return to their conventional land use in future. In addition to possible psychological obstacles (novelty, poor forestry experience in the region) the willingness of farmers to start establishing forestry plantations is also limited by technical, financial, organizational, legal, institutional and environmental obstacles. One of the major holdbacks in starting SRF plantations is a long period between investments and the return. Quite frequently farmers miss political goodwill. Usually, forestry plantations that are not subsidized cannot compete with other ways of land use that are well subsidized. Quite often there is a shortage of the specialists and advisers consulting on SRF plantation issues. Land consolidation, setting up of cooperatives, making provisional contracts with large-scale users should improve conditions for rational use of labour, machinery and land, annual remuneration payments, development of road network, improved fire protection, etc. [12].

The economic assessment of energy plantation breeding is rather contradictory, though the prevailing opinion in Europe is that growing SRF plantations for energy purposes is far from giving profit all the time and that such economy branch should be subsidized by the state. Growing of SRF plantations is more motivated by a political–social–ecological aspect rather than an economic one. SRF plantations compete with other ways of land use, especially those of [12,13]:

- Traditional forestry, mainly, due to sawn timber produce.
- Agriculture, due to food products; other energy or fibre crops.

Economic targets of a traditional forestry enterprise are: to produce timber suitable for sawing as a higher price is paid for sawn timber compared with wood biomass. Furthermore, biomass is obtained during the cultivation of stands and from cutting waste. SRF plantations have an advantage that biomass is obtained in a shorter period. That is of a special interest to the regions of low woodedness [12,14,15].

The breeding of SRF plantations and the market of the produce available have to be planned in close relation [15]. The demand of plantations is determined by market development, the need for activities alternative to agriculture and political decisions (especially in the field of sustainable energy). The main market for SRF plantations is: the market of cellulose, plywood and fibreboard industry; firewood and woodchips market (to produce electric or heating energy required both by individual users and towns or districts). The local market of broad secondary use (pole and fence production, basket weaving, etc.) is also important for SRF plantation economy. Following the present prices of selling biomass to the enterprises producing electric or heating energy, or cellulose SRF plantations can be economically sound only when the annual yield of 12 t of dry matter/ha is achieved [14,15].

In future the energy market can have even higher potential than the cellulose industry, as the tendency is to reduce the use of fossil fuel, increase the use of local resources of renewable energy (RE) as well as diminish the greenhouse effect and acid rain. The development of SRF plantations for energy purposes mainly depends on the political goodwill of individual countries—it is not easy to reorientate yourself from the depleting fossil fuel to the sources of renewable energy (RES) [12].

In certain territories (less fertile growing locations, hilly areas, territories with underdeveloped road network) sometimes it is considered appropriate to breed plantations of longer rotation (15–20 years) and one stem plants to produce plywood and sawn timber. The purpose of energy plantations is as follows [12,14,15]:

1. The main purpose is:
   - To obtain raw material for energy production which would replace imported oil and coal at least in part.
   - To grow timber for different purposes (as a raw material for chemical processing, paper industry, fibreboard manufacturing and timber assortments).
2. Supplementary functions are:
   - Environmental function (for utilising wastewater sludge, groundwater depuration), protective strips for water bodies.
   - Sanitary-hygienic function (reduction of carbon dioxide and different pollutants in the air).
   - Economic function (more profitable alternative agricultural production, given the surplus of food products).
   - Profitable use of areas not suitable for agriculture while obtaining valuable produce in worked out peatbogs and quarries, dumping grounds of wastewater sludge, wetlands and recultivated scrap-heaps.

Straw is considered to have the highest potential as the waste of vegetative origin [16–18]. Its fecundity depends on the type and variety of cereals, climatic conditions, etc. [17,18]. There is no statistical data on the fecundity and yield of straw in LIT. While calculating the potential of straw production the experts use the statistical data on the land areas of cereals and grain productivity [5,16]. According to the statistic data (year: 2010) there are about 1012.02 thousand ha cereals in LIT [19]. Fecundity of straw is related with grain productivity. The most prevalent are wheat and barley areas. Their productivity is 3–4 t/ha. The experts from different countries suggest that the ratio between straw and grain productivity can vary from 0.6% to 1.2% depending on the type and variety of plants. Different assessments established that the annual potential of straw production is up to 4 million tonnes. Around 15–20% of this amount is left during harvesting, more or less the same amount is used for feed, bedding, up to 1% is used for other needs (vegetable growing and energy production) and around 60% of straw yield is left unused at all (ploughed down or even worse—burnt in the fields) [16,18]. This amount of straw (about 2.4 million tonnes) can be used for energy purposes (biofuel and energy production) [16]. The energy value of available straw accounts for around 870 thousand toe. Straw collection

is reduced by harvesting and tillage technologies used on farms; straw is chopped by grain harvesters and then incorporated into the soil. It is done in order to finish harvesting operations as soon as possible and to sow a new crop. There is a common opinion that this method reduces fertilizer use and increases soil humus amount. The research carried out elsewhere in Europe (Denmark, Spain) demonstrates that ploughing down the straw is expedient only in the soils of certain composition. The required effect is not achieved in loamy and clay soils as there are sufficient cereal remains after harvest (crop roots, stubble, ears, chaff, etc.). These remains account for 15–20% of the straw yield and they are sufficient for keeping the soil humus level.

Lithuania has a great potential for expanding local biofuel market and reap the derivative effects in relation to energy and environment on faster growing biomass like SRF, SRC and straw. Energy forestry and agro-residues lessen the environmental impact connected to energy production and consumption and contribute to meeting Lithuania's international obligations for the discharge of greenhouse gasses (carbon dioxide, methane, nitrous oxide), sustainability and biodiversity.

This review contains practical information on the experience acquired by establishing SRF plantations in LIT as well as utilisation of energy forestry and agro-residues for heat and power. The paper details cultivation and harvesting of SRF, rationality of production, types and applications of industrial combustion systems. Other important issues, including support and incentive mechanisms and examples of successful implementation, are also discussed.

2. Short rotation forestry plantations in Lithuania

2.1. Historical background

So far LIT has accumulated rather little scientific and practical experience regarding SRF plantations. Though the problems of growing willow (osier) (*Salix* L.) plantations in LIT had been analysed in early 1954 [20] and later in 1978 [21], however, broader research was started only in 1989 when the field collection of willow was established in the production site Noreikupis (Šakiai District) of Kaunas AB "Žilvitis" (see Fig. 1). After several years the second plot of the willow collection was established in the plantation of AB "Vilda" in Alytus town. Since 1997 this collection has been expanded.

Fig. 1. Willow plantation growing in the fields belonging to wicker weave manufacturer Kaunas AB "Žilvitis" (Noreikupis, Šakiai District).

These issues were studied by the Institute of Botany [20,22,23] and the Lithuanian Institute of Forestry [24–27]. Gradeckas [28] has announced the following conclusions:

- Energy plantations of willows (osiers) for biomass production are expedient to grow in cultured sandy loam soils that are amply fertilized.
- The cheapest and very effective fertilizer is wastewater sludge with an additional application of potassium mineral fertilizers.

The plantations of poplar-aspen (*Populus* L.) and their hybrids have been investigated by Yu et al. [29]. So far, there have been only a few trials in LIT to breed poplar plantations valuable in terms of science-economy (e.g., a black poplar plantation (*Populus nigra* L.) planted in Telšiai district in 2004; and an experimental plantation of quaking aspen (*Populus tremuloides* Michx.) planted on the initiative of the Service of Genetic Resources, Plant and Breed Material in Dubrava Experimental and Training Forest Enterprise (Kaunas District) in 2006). Besides the representatives of these two genera belonging to the same family *Salicaceae* Mirb., breeding other tree or shrub species in short rotation forestry (SRF) plantations is hardly worth because many species cultivated in a warmer climates will freeze in LIT where climatic conditions are cold or due to a shorter vegetation period they cannot produce sufficient amount of biomass. In general, before recommending farmers to cultivate the species and their varieties introduced from foreign countries their approbation for Lithuania's climate conditions is necessary [12].

The main factors limiting introduction are critical temperature ranges (the lowest wintertime temperatures, early and late frosts, diseases and genetic characteristics of species). Therefore, the introduction of foreign species comprises both the process of a species relocation and related naturalization. It is important for the introduced plants to have the local climate corresponding to the climate of their natural habitat [12].

Salicaceae—it is a family of summer-flowering trees and shrubs which consists of three genera: aspen, poplar—*Populus* L., willow, osier, sallow—*Salix* L. and *Chosenia* Nakai. There are about 350–500 species of this family all over the world, found in the moderate and cold climate zones. In LIT one species of aspen (*Populus* L.) and eighteen species of willow, osier and sallow (*Salix* L.) grow naturally [12]. Willows, osiers and sallows are distributed naturally in different biotopes, therefore, they can be found on the banks of rivers and lakes, in wetlands and forests, outlying fields and sand dunes. In addition to the eighteen naturally grown species in LIT there are three introduced species; 11 subspecies, 12 varieties, 67 forms and 31 hybrids are distinguished. The stem and trunk is developed best by willows that turn into trees. They can be short-trunked and very branchy. Shrubby willows have several perennial stems of more or less equal diameter and height; their number in a shrub depends on the species in question and conditions in the growing location.

The data of preliminary research carried out in the Institute of Botany suggests [12] that a variety "*Tordis*" (a hybrid of common osier and willow *Salix schwerinii* (*Salix viminalis* × *S. schwerinii*) × *S. viminalis*) demonstrates fair adaptability and productivity under Lithuanian conditions. Recently the mentioned and related species and varieties of willow (osier) are or have already been used to establish short rotation forestry (SRF) plantations, or are being tested under local Lithuanian conditions.

2.2. Experience acquired by establishing SRF plantations

As the major experience in LIT so far has been acquired in terms of establishing willow clone (mainly *S. viminalis*) plantations, which are also considered the most appropriate ones, the

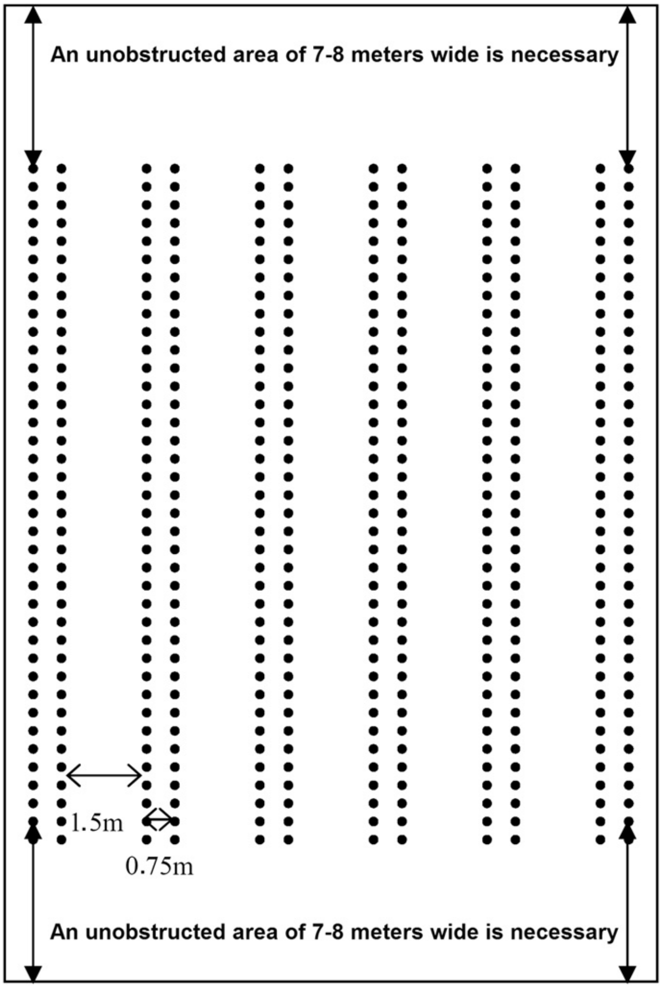

Fig. 2. Willow planting scheme [12].

main technological requirements are presented namely for breeding, maintenance, protection and use of willow SRF plantations. The analysis of experience in EU countries shows that it is purposeful to grow forest plantations only in growing locations with rich soils [4,30,31–45]. These findings are in line with previous research undertaken by Lithuanian scientists [12,20–28].

Rather high potential of territories suitable for SRC and SRF plantation breeding is observed in Mažeikiai (area—1220 km^2), Akmenė (844 km^2), Joniškis (1152 km^2), Pakruojis (1316 km^2), Pasvalys (1289 km^2), Kupiškis (1080 km^2), Panevėžys (2178 km^2), Kėdainiai (1677 km^2), Šiauliai (1807 km^2) and Marijampolė (755 km^2) municipalities [16]. In LIT land areas suitable for this purpose will in all cases be of soil productivity index rating higher than 32 (39), i.e. productivity higher compared with land designated for usual planting of forest. According to moisture conditions growing locations of ''N'' and ''L'' hydrotops can be suitable.

Different soils (sand, sandy loam, clay or loam) are suitable for breeding common osier (*S. viminalis*) plantations [38–45]. Soil pH level should range from 5.5 to 7.5 [12]. Willows will grow fast, if groundwater is not deeper than 1.0 m. Under conditions in LIT, it is recommended to breed plantations in locations of flat landscape as it is problematic to apply breeding, maintenance and harvesting technologies in hilly areas; soil erosion risk increases. The soils of higher fertility (productivity) guarantee a higher plantation increment, therefore, before breeding plantations in unfertile soils the economic effect must be calculated very thoroughly: most often such decision is detrimental. Common osier plantations can be bred in the fields that are flooded temporarily in spring (but not in wetlands!) as this plant likes moisture. Peaty soils hardly retain sufficient amount of moisture during dry periods, therefore, it is not recommended to plant willows in absolute peatbogs. Heavy, clay soils can be particularly productive, especially when there are great amounts of organic materials. In fact, at the beginning of cultivation willow roots have weaker development, but later the shrubs establish themselves and grow fast as such soils retain sufficient amounts of moisture. In order to ensure good productivity of plantations in fertile, humus rich soils, it is important to organize timely eradication of intensively growing weeds [20–28]. An obtained findings are very similar to that recorded for the most of EU-27 countries and especially Sweden [44,45].

In Lithuania, it is best to plant willows in the first half of May, when soil has sufficient amount of moisture and the air temperature rises fast. Earlier planting is not recommended due to frequently occurring spring frosts. If soil has enough moisture, a willow plantation can be bred even in the beginning of June. Small furrows are made by a potato ridger or other implement. Willow cuttings are planted in twin rows indicated by furrows. Experience suggests that in the case of small planting area (up to 10 ha) it is possible to establish a plantation manually. Three persons can plant one hectare of land in one day. The cuttings are pushed directly into loose soil by hand leaving about 1 cm above the surface. In order to push them into the soil easier it is advisable to use a metal bar or other device and make a narrow hole beforehand. The later (end of spring–beginning of summer) it is planted, the deeper cuttings have to be pushed into the soil. In exceptional cases they can be covered with approximately 1 cm thick layer of soil.

The distance between twin-rows is recommendable to be 0.75 m and the distance between the seedbeds—1.5 m (Fig. 2). The spacing between seedlings in rows should be about 0.60 m. In that case, approximately 15,000 cuttings are needed to plant in one hectare of land.

Willow plantations are harvested in winter by modified maize harvesters or special machinery. The harvesters chop stems into chips and pour them into the wagons. Usually, special harvesters can cut one hectare in 1.5 h. In a compact territory (when the distances for machinery transportation are relatively short) one harvester is enough to cut 1000 ha of plantations. The chips produced (green mass of 50% moisture) can be transported to the district boiler-houses for burning.

Fig. 3. Biofuel boilerhouse of 15.3 MW capacity in Naujoji Akmenė town (DH renovation project in Akmenė region, when old central heating networks were modernised in Naujoji Akmenė, Akmenė and Papilė towns).

In 2010–2012, the number of boiler-houses using wood waste as fuel is increasing fast (Fig. 3) in LIT as wood fuel is relatively cheap and hardly pollutes the environment. The growth of demand in the wood waste market should result in price increase for this fuel. Currently, there are more than 30 growers who have planted fast growing willow plantations in 2012. Plantations for energy purposes have future in terms of satisfying energy (heat) needs of farmers themselves as well.

In addition to biomass production growing plantations of poplar (aspen) and other fast growing trees can produce the timber of higher value used in sawmilling industry, cellulose industry, paper and plywood manufacture. However, Lithuanian farmers are more inclined to gain lower but faster profit from forest plantations rather than wait for 10–20 (or more) years and achieve the produce of higher value.

2.3. Examples of successful implementation: forest plantations for energy purposes in Gražiškiai Eldership, Vilkaviškis district

Location: Gražiškiai and Vištytis Elderships, Vilkaviškis D., LIT.

With more and more heating systems being renovated the need for small biofuel boiler-houses and plantations of energy plants increases. In 2006 when the community started the initiative of alternative energy, there were only 300 ha of such plantations in LIT. At that time there were 5 boiler-houses using biofuel and producing 4.5 MW of heat in Vilkaviškis district [46]: three of them

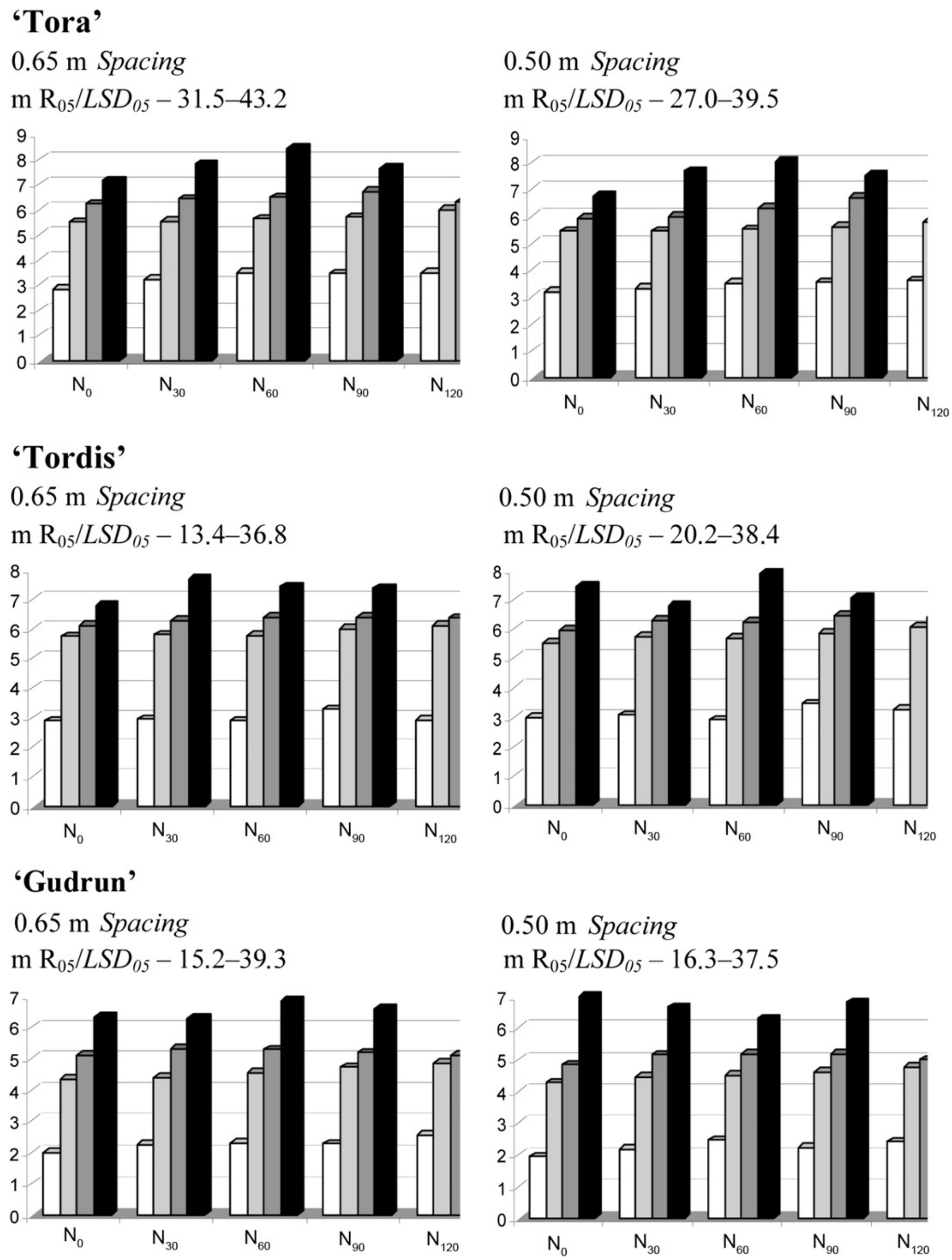

Fig. 4. Secondary growth of willow stems after cutting (the willows were grown without fertilizers N_0 and fertilized with nitrogen: N_{30}, N_{60}, N_{90} and N_{120}) [37].

belonged to schools and two were town boiler-houses. There was also a special straw burning boiler heating Alvitas community house and the community in Keturvalakiai was installing the line of straw processing (briquetting).

Project progress [46]: in the beginning of the activities the community consulted the specialists for advice who provided a lot of valuable information on how to start a willow plantation, tend and harvest it. Preliminary operations for establishing plantations had to be started as early as in summer before planting the forest: the land was tilled, the weeds eradicated thoroughly. According to the specialists the efficient control of weeds from the beginning can ensure the productivity of a willow plantation for the entire period of its growth. Having exterminated the weeds in spring the fields were fertilized before planting. The willows were planted in the first half of May when the ground was still moist but there was no risk of frosts. To plant one hectare 15 thou units of willow seedlings are needed: the rods of 20 cm in length were pushed into the soil in twin rows leaving sizeable intervals.

The seedlings start sprouting up in 1–2 weeks thus the next intensive stage of two years is weed eradication, as poor tending of the seedlings during the first two years can determine poor productivity of the plantation. Later, when the willow spreads out, weeds cannot choke them, therefore, maintenance work is reduced. According to the specialists, even in unfertile soil willow shoots grow up to 1.5–1.8 m during the first year and after 3 years their height reaches 5–7 m.

In order to achieve faster branching of the shrubs during the second-third year after planting the seedlings that have taken root are cut. Even at that time the rods cut can be used as biofuel or as seedlings for propagation. The first yield of an energy plantation is harvested after four years; later, during 30–40 year period willow branches are cut every 4 years, i.e. a plantation yields up to ten harvests [46].

In accordance with the agreement between the community and the project finance providers the willows will become the property of the farmers after the project is finished. However, according to the additional terms of the agreement the farmers have to propagate and render willow shoots for free to other farmers willing to start willow growing on the same or similar conditions. At the start of the activities the seedlings were distributed to 11 families and in 2010 they were distributed to 200 families.

During the project the community purchased the equipment for planting and tending of willow plantations and for rod chipping: a tractor, a branch chipper and a chainsaw. Even during the first year with the help of this machinery reclamation ditches were cleaned, low-value shrubs eradicated and during the entire period of the project 300 km of reclamation ditches were cleaned. At the moment there is an agreement made with the municipality regarding the maintenance of 1200 km of ditches. The chaff obtained was used to heat community premises, the township's library and the parsonage. The community has already made provisional agreements and undertaken to provide a larger amount of chaff for a line of biofuel briquette manufacturing which is planned to be erected in the district. However, biofuel is not sold already as the willows are not cut yet and the chaff produced of low-value trees and shrubs during the cleaning of ditches is of different size [46].

With a view to manifesting the community members the benefit of using biofuel special biofuel boilers and the heating system have been installed to heat the community house, the renovation of the community premises has been carried out for regular use. There were four training sessions-seminars organized for farmers on the issues of growing forest for energy purposes and maintenance of buffer zones, cooperation and other topics urgent for the community as well as a leisure camp for children. The information on the project was distributed actively; the community has been constantly receiving questions on how to grow energy forest from private and legal persons.

Project strengths [46]:

- The plantation requires a lot of tending during the first year and later its tending is minimal.
- The activity is suitable to develop on unfertile and abandoned land.
- The cooperation between small-scale farmers was stimulated—sharing of machinery for tillage and shrub chipping.
- Rendering of seedlings to other families stimulated more active communication within the community.

Project weaknesses [46]:

- Energy forest is not possible to plant in reclaimed territories—willow roots destroy land reclamation installations.
- Huge amounts of pesticides are used for weed control during the first year.

2.4. An overview of R&D activities for SRC-for-fuel

A lot of significant research has been done at Vokė branch of the Lithuanian Research Centre of Agriculture and Forestry. According to the data of agrochemical analyses the soil of the experimental location is sandy loam on calcareous fluvio-glacial gravel—*Haplic Luvisol (LVL)*. Agrochemical indicators: pHKCl 5.6–5.7, hydrolytic acidity—2.9–3.8 mequiv/kg, sum of sorbed bases—6.4–7.2 mequiv/kg of soil, humus—1.97–2.1%, and potassium 167–180 mg/kg of soil [47]. The preceding crop before willow was oilseed radish. The crop planted was (spaces between twin rows—75 cm, spaces between plants in rows—65 and 50 cm) the cuttings of “Tora” and “Tordis” varieties of common osier (*S. viminalis*) and “Gudrun” variety of willow *Salix dasyclados*.

In the spring of 2005 the cuttings of “Tora”, “Tordis” and “Gudrun” varieties were planted. During vegetation the increment of their shoots depending on planting density and nitrogen used for fertilization was analysed (Fig. 4) [47].

Fig. 5. 2.5 MW straw-fired HOB installation in Akademija town.

During the first year the cuttings of different willow varieties produced different amount of offspring shoots. The willows that had been cut in spring regrew quickly, the offspring shoots were developing very fast. One plant produced 8.5–12 shoots on average. During one year the regrown shoots of the willows "Tora" and "Tordis" reached the average height of 3.20–3.40 m (Fig. 4).

As it was already mentioned nitrogen fertilizers had huge influence on willow growing. The shoots of "Tora" variety planted at 0.65 m spacing between plants in a row and fertilized by nitrogen at N120 were as long as 1.92 m on average or 0.59 m longer than those with no nitrogen fertilization.

Detailed studies on growing, treating and burning herbaceous and woody energy plants have been conducted in Aleksandras Stulginis University (ex. Lithuanian University of Agriculture) since 2000 and developed their methods annually [14,48–51].

3. Experience acquired by developing of agro-residues market

Lithuania is the largest and southernmost of the Baltic States, which: (1) is highly dependent in their total primary energy supply on energy imports from other jurisdictions (mainly natural gas from Russia); (2) has significant potentials for biomass-to-energy and straw-to-energy in particular, and (3) emerging "on-the-ground" straw-based heating systems.

Historically, using straw for fuel in LIT was started more than fifteen years ago when a straw using boiler-house of 1 MW capacity was erected in Joniškėlis agricultural college, Pasvalys District with the help of EA Energy Agency (LIT) and the Danish Energy Agency (Denmark) in 1996. According to the data of the Institute of Agricultural Engineering, in 2000, 7 thousand tonnes of straw were used for fuel. In 2008 straw using boiler-houses operated both in Pasvalys District and the settlements of Juknaičiai, Šilutė District and Kuigaliai, Jonava District as well as in the agricultural companies of Pakruojis, Švenčionys, Jonava and Anykščiai Districts. Totally, about 60 straw-fired heat-only boilers (HOBs) have been installed in LIT in 1996–2012. The amount of straw used for heating purposes comprised about 20 thousand tonnes in 2008 however, it is a small amount as 500 thousand tonnes of straw could be used for fuel every year. In accordance with the data presented it can be stated that having increased the use of straw up to the mentioned 500 thousand tonnes every year in case of LIT such type of fuel would be an important task in implementing the provisions of the National Energy Strategy [52].

Due to NG price fluctuations in 1996–2005 further introduction of fully automatic straw-fired technologies in the country was under consideration. This period marked the development for small boilers (50–375 kW), which were mainly installed on family and pig farms. The second straw-fired automatic HOB of 2.5 MW was installed in 2007 in Akademija town (Fig. 5) and is currently the largest functioning system of this kind in LIT [16].

Fig. 6. Straw shredding equipment made by Lithuanian domestic producers: (a) JSC "Radviliskis Machine Factory" and (b) JSC "Axis Technologies".

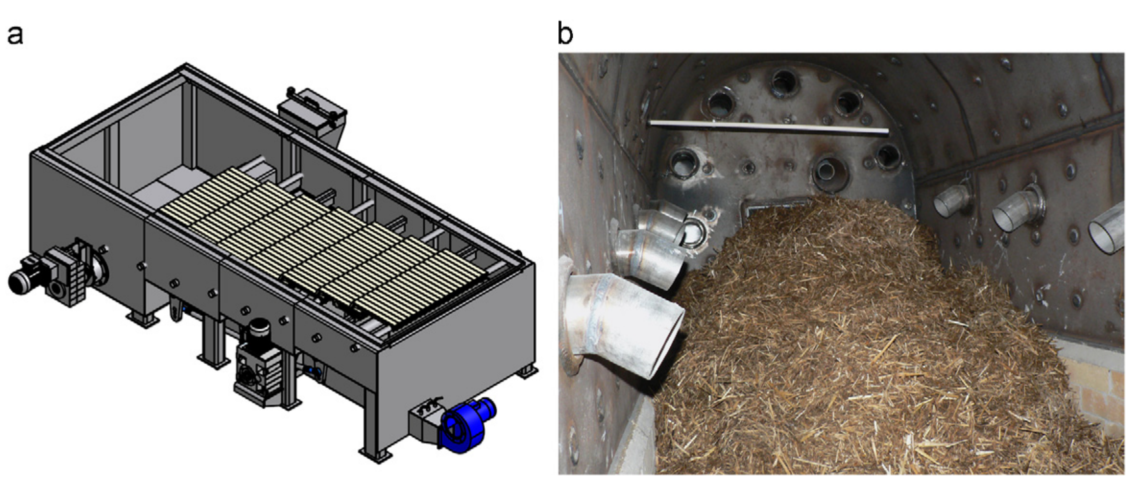

Fig. 7. Straw fired boiler: (a) grate stoker and (b) view from inside of the furnace (manufacturer: JSC "Axis Technologies").

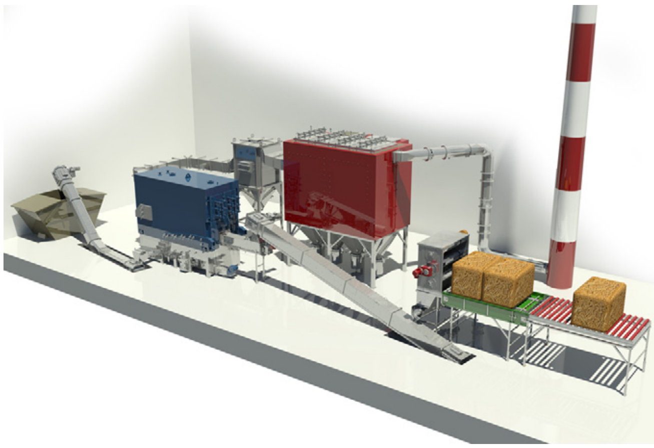

Fig. 8. Fully automatic straw firing system in Kazlų Rūda town boiler house (manufacturer: JSC "Axis Technologies").

In 2004, JSC "Radviliskis Machine Factory" started to produce straw pelletizing equipment. Mixed biomass/straw pellets production is advantageous due to straw surplus in LIT and its low cost. Straw pellets are a new product on the pellet market, and no national quality standards exist. Together with JSC "Axis Technologies", both companies produce straw shredders intended to be applied in fully automatic straw firing systems as well (Fig. 6).

There are three straw-fired boiler manufacturers in the country: JSC "Umega" (130–600 kW batch-fired boilers), JSC "Kalvis" (30–120 kW straw pellet-fired boilers), and JSC "Axis Technologies" (1 MW fire tube boiler— see Figs. 7 and 8).

Currently JSC "Axis Technologies" is the only national manufacturer in LIT producing fully automatic straw firing systems. The successful start-up of pilot technology of heat production (Fig. 8) was launched in September, 2012.

Due to the low demand and lack of experience working with agro-biomass waste suppliers, only a few companies in the country could agree on long-term contracts to supply straw fuel for 1–5 MW HOBs. The price for baled straw in 2011–2012 varied from 140 LTL/t (40.58 EUR/t) to 180 LTL/t (52.17 EUR/t) (abbreviation LTL stands for Lithuanian Litas (local currency); 1 LTL = 0.29 EUR) with a higher price for large rectangular bales due to more energy consuming process for straw gathering and pressing. Similarly as in other former republics of the Soviet Union, in LIT 90% of the collected straw is pressed into round bales [16,53–55].

Having calculated a factual cost and knowing that 3.6 MJ of heat energy equals to 1 kWh it is easy to compare the cost and calorific value of straw and traditional fuel. The expenses for pressing, collection, transportation of straw bales from fields and loading them in storage places account for 50–70 LTL/t (14.5–20.3 EUR/t), the heat produced is 14.71 MJ/m^3 and the cost of one heat unit is 1.71 ct/kWh (0.5 ct EUR/kWh). The cost of transporting small straw bales is 90–100 LTL/t (26.1–29 EUR/t), 14.71 MJ/m^3 of heat is produced and the unit cost is 2.45 ct/kWh (0.71 ct EUR/kWh). The expenses of producing straw briquettes and pellets account for 220–240 LTL/t (63.77–69.59 EUR/t), the heat produced is 15.26 MJ/m^3 and the cost of one heat unit is 5.66 ct/kWh (1.64 ct EUR/kWh). Having compared it with other energy resources we can see that the cost of natural gas for fuel is 0.76 LTL/m^3 (0.22 EUR/m^3), its calorific value is 7200 MJ/m^3 and the price per heat unit is 7.67 ct/kWh (2.22 ct EUR/kWh). Boiler oil respectively: fuel cost is 600 LTL/t (173.9 EUR/t), calorific value—39 MJ/m^3, price—5.54 ct/kWh (1.61 ct EUR/kWh).

According to the data presented we can see that during straw combustion the price per heat unit produced is 2 times lower compared with firewood (the price of birch firewood is 80 LTL/t (23.19 EUR/t), its calorific value—7200 MJ/m^3 and price per heat unit—4.0 ct/kWh (1.16 ct EUR/kWh)) and it is 3 times cheaper compared with imported boiler fuel. One tone of straw used for fuel can replace 0.4 t of boiler fuel and reduce fuel expenses by more than 160 LTL (46.37 EUR). If the whole available amount of straw is used for fuel, the fuel expenses could be reduced by up to LTL 80 million per year (EUR 23.19 million per year).

Naturally, if the total sums are taken, the prices make an unequal balance. Straw briquettes and pellets are slightly more expensive fuel than firewood; however, they are cheaper than natural gas. With prices for natural gas going up it could be reasonable to believe that the demand for biomass fuel produced from straw increases as well. Therefore, the production of fuel pellets and briquettes could become an additional business for those farmers who have huge amounts of straw. In order to reduce expenses for heat energy it is necessary to spend more time and efforts in explaining and propagating the use of unconventional cheap local fuel straw alongside traditional local wood fuel.

Currently, straw is burned in relatively small boiler-houses and the energy produced is used for heating small buildings [56]. The system of straw collection and using it in major boiler-houses or cogeneration power plants is not developed in LIT yet. Hence, the use of wood fuel in households has changed marginally over the years and it has been stable for the last three years; it accounts for 60% of all wood fuel consumption in the country. It is credible that the wood fuel used in households will remain on the same level in future (up to 2025) (Table 1).

There is no statistical data on the amounts of straw produced; nevertheless, it is possible to make rough calculations regarding the amount of straw according to the yields of cereals and the balance between straw and grain for different types of crops. The results of this calculation for the harvest of 2010 are presented in Table 2 [19]. On the supposition that 60% of straw are ploughed down and a half of the remaining quantity is used in animal

Table 1
Forecast of heat energy generation from renewable energy sources in Lithuania.

No.	RES type	Resources consumption		
		2013	2014	2015
1.	Timber waste and firewood	347.8	350.6	353.4
2.	Agricultural residues (straw)	18.2	22.0	25.8
3.	Energy crops	28.2	36.6	45.0
4.	Municipal waste	57.2	57.2	85.8
5.	Biogas	4.9	6.0	7.2
6.	Landfill gas	3.9	3.9	3.9
Total		462.0	478.2	523.1
Including transformation losses		394.3	408.2	446.5
% Of national heat consumption		30.3	31.4	34.3

Table 2
Crops and amount of straw in 2010 [19].

Type of crop	Grain yield (thou t)	Ratio straw/grain	Straw yield (thou t)
Winter wheat	1250.4	1	1250.4
Winter triticale	217.7	1.2	261.24
Rye	87.0	1.5	130.5
Winter barley	37.4	1	37.4
Winter rapeseed	177.6	2	355.2
Spring wheat	460.0	1	460.0
Spring barley	512.6	1	512.6
Spring triticale	40.7	1.2	48.84
Oats	93.9	1.3	122.07
Total			3656.45

Table 3
Elemental composition and calorific values of straw of field crops [56–62].

Name	Elemental composition of dry matter (%)							Calorific value	
	C	H	O	N	S	Cl	Ash	Upper	Lower
Barley straw	39.92	5.27	43.81	1.25	–	–	10.30	17.31	16.24
Wheat straw	43.20	5.0	39.40	0.61	0.11	0.28	8.9	17.51	16.49
Bean straw	42.97	5.59	49.30	0.83	0.01	0.13	5.93	17.46	16.32
Maize ear stalks	46.58	5.87	45.46	0.47	0.01	0.21	1.36	18.77	17.58
Maize stems	43.65	5.56	43.31	0.61	0.01	0.60	5.58	17.65	16.52
Sunflower stems	41.71	5.54	46.58	0.62	–	–	4.65	19.23	18.10

Table 4
Summary of capacities typical for different biofuel combustion technologies [62–68].

Combustion technology	Minimal capacity (MW)	Typical capacity (MW)
Stationary grate stoker	0.01	0.05–1
Moving (travelling) grate stoker	0.8	2–15
Fluidised bed combustion	1	>5
Circulating fluidised bed combustion	7	>20
Fuel gasification	0.3	2–15

husbandry the unused amount of straw equals to 20% or 731 thousand tonnes. Having assessed the fact that about 10% of the remainder straw will be used for producing substrate for mushroom growing, vegetable production and other purposes the remaining 660 thousand tonnes of straw can be used for fuel. As the calorific capacity of 1 t of straw is 0.334 toe, the energy value of straw fuel equals to 145.1 thousand toe.

The analysis of the change in variation of crop areas during the last three years showed an insignificant increase of cereal areas (2–5%) [19]. It is supposed that in future with a fast increase of biodiesel fuel production the areas of rapeseed crop will increase as well. Therefore, a forecast can be made that the amount of straw produced would not change reasonably compared with the present amount. Thus, the supplies of straw fuel should increase insignificantly in future as well. Recently increasing prices for natural gas and constantly increasing oil prices on the international market will make straw fuel more attractive.

In order to choose the straw which is suitable for energy purposes it is necessary to know the chemical composition and calorific value of the biomass of different maturity. It can be seen from the data submitted in Table 3 that barley straw has higher ash content—10.3% compared with 1.36% achieved while burning the stalks of maize ears [57–61]. All types of straw contain a relatively small amount of sulphur—around 0.11% or less. Chlorine accounts for a slightly higher amount—starting from 0.60% in maize stems and up to 0.13% in field beans [57–61]. That fact can be explained by the application of fertilizers during plant vegetation period.

4. Overview of biofuel combustion technologies used in Lithuania

In view of huge diversity of biofuel characteristics different technologies can be applied for its combustion [56]:

- Grate firing. Grates of different designs are used (light chain wheel fire grate; level, tilt, reciprocating fire grate; large flake chain fire grate; small flake chain fire grate; cross-beam chain fire grate), which can be divided into two groups—stationary and moving ones.
- Fluidized bed combustion (FBC) is a combustion technology used in power plants. FBC systems fit into essentially two major groups, atmospheric systems (FBC) and pressurized systems (PFBC), and two minor subgroups, bubbling (BFB) and circulating fluidized bed (CFB).
- Gasification. It is a process that converts organic based carbonaceous materials into CO, H_2 and CO_2. This is achieved by reacting the material (biomass) at high temperatures (>700 °C), without combustion, with a controlled amount of oxygen and/or steam. The resulting gas mixture is called syngas and is itself a fuel.

A certain range of boiler capacities has appeared for each combustion technology to have the use of an individual technology expedient technically and economically. Under Lithuanian conditions the boilers with up to 5 MW capacity use the flake type burning (on the grate) technology in general and the technologies of fluidised bed combustion are usually applied for large boilers. As well as in the Scandinavian countries the fluidised bed combustion technologies for burning wood fuel have become popular in the Baltic countries, Poland and Russia.

In different fields it is expedient to use the boilers of certain capacity, the most appropriate technological solutions and the required level of automation (Tables 4 and 5).

The poorer quality and the more different fuel are used, the more sophisticated technological scheme of combustion equipment and the entire boiler-house is. The main technological section of a boiler-house is a boiler with a furnace. Combustion processes and the furnace design depend signally on the characteristics of fuel (calorific value, moisture, etc.). With a view to choosing the most appropriate equipment it is necessary to assess the characteristics of biofuel combustion.

The comparison of grate firing and fluidised bed technologies is presented in the Table 5 [62–69].

Among the locally available technologies used for heat and power production, travelling grate combustion technologies have the biggest potential in terms of operation experience as well as bubbling fluidised bed technologies have received recognition in Lithuanian market because of their flexibility to fuel moisture and fraction size, efficiency of combustion and prevention of NO_X formation [66–68].

5. Support schemes and mechanisms for bioenergy

The main documents that determine bioenergy use and development in Lithuania include: (1) the Law on Energy [70], which regulates LIT energy sector and is harmonised with EU legislation; (2) supplementary Legal Act No1474 to the Law on Electric Energy [71], which creates incentives for renewable electricity purchase (i.a. electricity certificates); (3) the Law on Heat Sector [72], which i.a. regulates combined heat and power

Table 5
Comparison of grate firing and fluidised bed technologies.

Characteristics	Grate stoker		Fluidised bed	
	Travelling grate	Vibrating grate	Bubbling	Circulating
Design characteristics				
Design simplicity		+	+	
Design compactness			+	+
Time of installation				
Cheaper investments	+	+ (up to 50 MW)	–	–
Operating characteristics				
Control of combustion process				+
Response to load change		+	+	+
Option of continuous minimum load regime				
Maintaining vapour parameters at fuel characteristic change			+	+
Option of continuous operation				
Start-up/stopping time		+	+	+
Reliability		+	+	+
Simplicity of handling	–		+	+
Operation experience	++	+		
Fuel characteristics				
Flexibility to fuel moisture		+	++	++
Flexibility to fuel fraction size	+	+	++	+
Resistance to fuel slagging			+	+
Erosion of boiler tubes				–
Protection against explosion				
Efficiency characteristics				
Efficiency of fuel combustion		+	++	++
Control of air surplus			+	+
Capacity of air fan			–	–
Load uptake			–	–
Environmental indicators				
Prevention of NO_X formation		+	++	++
Option of reducing sulphur oxides			+	++
Solid particles emission			–	–

Note: "+" indicates advantage, "–" indicates disadvantage, and "empty" not distinguished.

(CHP) production on biomass; (4) the Law on Renewable Energy [73], which ensures sustainable development of RE; (5) National Energy Strategy [52].

5.1. Legal acts providing for development of SRF plantations

In implementing the provision of Article 48 of the National Energy Strategy [52] "With the view of using the local energy resources at the maximum and thus reducing fuel imports and the use of gas in producing electricity and central heating, creating new workplaces and reducing CO_2 emissions" a programme for a wider introduction of solid biofuels to produce heat and electricity will be prepared and implemented. It will provide for:

- Establish energy plantations and expand their areas on a constant basis; to provide about 45 ktoe for energy needs in 2015 and about 70 ktoe in 2025.

At the moment the process in progress is unsatisfactory. The support for starting energy plantations has been reduced twofold since 2008 compared with the prior period. Furthermore, the legalization of plantation establishment has remained very complicated and awkward. The issue of cultivation and biomass harvesting machinery and technology has not been solved. A separate programme for intensifying energy plantation breeding is necessary, which has to provide for:

– The issues of land use (regarding long-term lease).
– Legal regulation of plantation establishment.
– Support to plantation establishment and cultivation.
– The use of wastewater sludge and biofuel ash for fertilizing plantations.
– Purchasing of specialized machinery.
– Consultations for those wishing to start this business.
– Other.

5.2. Legal acts providing for the use of straw biofuel

In implementing the provision of Article 48 of the National Energy Strategy [52] (article's title—see Chapter 5.1.), a programme for a wider introduction of solid biofuels for heat and electricity generation will be drafted and implemented envisaging:

- The creation and implementation of the logistics system for gathering, storage, transportation and use of straw in enterprises providing district heating. According to experts, straw remains unused in the agricultural sector of Lithuania and their energy value may amount to approximately 120 thousand toe by 2025 (investments amount to nearly LTL 60 million (EUR 17.4 million)).

The experts of this study estimated the amount of straw accumulating currently and established that the amount of straw

available for energy purposes accounts for about 2.4 million tonnes, the energy value of which equals to approximately 870 thousand toe. To assimilate the potential of such scale both a logistics system and new capacities for energy production must be established which can operate by using only straw. Political decisions are required for the establishment of such power-plants. It is best to construct them in cooperation with the industries requiring huge amounts of heat (i.e. manufacture of insulating materials).

6. Facilitating and hindering factors for SRF-to-energy and straw-to-energy in Lithuania

6.1. Political and legislative factors

The legal basis for renewable energy and bioenergy production and use is created in LIT. From 2012, the major provisions of Law on Renewable Energy [73] became the key framework for sustainable development and use of RE. This Law is to encourage continuous technological development, innovation and consumption of RES, which is particularly important considering international obligations by LIT. Its other aims include environmental protection, substitution of fossil energy and reduction of energy imports [53].

The Legal Act No1474 to the Law on Electric Energy [71] promotes power plants below 10 MW. Network operators are obliged to secure priority rights for the transmission of renewable electricity. Operators of smaller plants using renewable electricity do not pay for the reserve power at the prices set by the National Control Commission for Prices and Energy (NCCPE). From 2010 this Law introduced green certificates to promote the purchase of energy from renewables and waste. For power plants below 10 MW, which use energy production and purchase incentives, a 40% reduction on the grid connection tax is applied to compensate the operators for incurred expenses and reorganisation of their energy networks [53].

The Law on Heat Sector [72] sets the amount of electrical energy purchased by the distribution networks operators as proportionate to the share of installed capacity and thermal power, as well as to the amount of thermal energy sold. The purchase rules are applied to combined heat and power (CHP) plants on biomass, if biomass constitutes at least 70% in the fuel balance, and if the rate of nominal electric and thermal capacity is at least 0.23. The Law guarantees purchase electricity prices until 2020 setting them at 6.4 or 7 € cents/kWh. While purchasing heat from independent suppliers and under equal heat prices the priority should be given to renewable heat. However, the energy purchase from CHP plants has not been completely settled. The amount of purchased electricity is proportionate to the amount of energy provided to consumer, and this amount is not the same at the end of the year. This limits the maximum installed electrical capacity since there is no compulsory purchase of thermal energy. Moreover, it prolongs the return time on investments due to smaller income from the energy sale [53].

6.2. Financial and economic factors

Key factors determining the rate of biomass-fired HOBs adoption in LIT are cost related. Since most of the HOBs in LIT are imported, the investment risk is high, which reduces SRF and straw competitiveness with other solid biofuels, e.g. wood waste. To the extent possible the banks should reduce transaction costs to make loans more attractive and less risky, and thus support the implementation of SRF/straw-to-energy projects. Furthermore the efforts to reduce bureaucratic procedures, enhance access to loans, eliminate unnecessarily restrictive labour practices, and expand the availability of market-related information will stimulate the expansion of biomass-fired HOBs and their adoption in rural LIT [53].

The value of aforementioned types of biomass fuel depends on supply amounts and demand. One of the main factors determining straw availability is weather conditions: poor conditions lead to lower yields, and thus higher demand and prices [53].

Another important constraint for the development of biomass based heating is the lack of financial resources (e.g. investment capacity) and funding support (e.g. subsidies) to switch from traditional fuel to biomass [74]. DH companies in LIT are mainly owned by municipalities but some of them are rented on the long term by private companies. CHP plants can also be owned by a DH company or a private company. However, clear and transparent procedures for private capital to enter DH sector are missing [74]. At the same time, within 2007–2013 EU Cohesion Fund allocates EUR 37 million for the modernisation of existing, construction and connection of new boiler houses and CHP plants, which opens new opportunities for biomass-fired installations [53].

6.3. Capacity and knowledge-based factors

In 2020 16.7 PJ (0.4 Mtoe) of DH in LIT are expected to be produced from solid biomass [74] with about the same figure for the heat in the non-DH sector. Heat production from solid biomass in off-grid systems is expected to grow steadily and remain the dominant renewable heat technology contributing 66% in total renewable heat output in 2020. If the current levels of solid biomass use for off-grid house heating prevail, substantially higher biomass quantities could be allocated for DH adding up to a potential 70% share of heat supply from biomass in 2020 [74].

In most cases in LIT many varied authorities of local, regional and national levels are involved in granting final permits for a bioenergy project start up [53]. As such important constraining factors to the adoption and expansion of biomass-to-energy systems include bureaucratic and time consuming procedures linked to obtaining construction and environmental permits. Moreover, since bioenergy activities are not envisioned by the spatial planning rules and procedures, every bioenergy project and its alternative must be evaluated individually [74]. In addition, the entire legal framework of spatial planning is currently not adapted to the development of bioenergy projects (e.g. no priority zones for bioenergy activities are envisioned, and only general procedures exist, which results in time inefficiency). A potential solution to the 'bureaucracy problem' could be a reduction in the number of authorities responsible for granting permits and financial support [53]. Project developers appear to be more positive when a single body co-ordinates several administrative procedures [74].

Universities and research institutions in LIT are important capacity builders and knowledge providers on biomass-to-energy systems [53,75–77]. The following areas are studied: technology development for the pollutant formation reduction with an emphasis on fuel combustion including energy crops and straw (Institute of Agro-Engineering LUA; Vilnius Gediminas Technical University; Lithuanian Energy Institute (LEI); Kaunas University of Technology (KTU)) [48,49,77–83]; experimental advancement of energy crop and straw-firing technologies and their compliance with EU norms and requirements [16,81]; straw conversion technologies (KTU; Aleksandras Stulginskis University, LEI, etc.) [15,16].

7. Conclusions

The potential to use SRF, SRC and straw for energy is significant in LIT. If developed sustainably, it could help the country

to combat its pressing environmental, economic, social and security challenges. The major facilitating factors include: (i) fast payback of biomass HOBs, (ii) interest of local and foreign actors in biomass-to-biofuel and biofuel-to-energy activities, (iii) significant bioresources potential, (iv) existence of national biomass equipment producers, (v) presence of national scientists in the field of bioenergy research with a potential for knowledge development and diffusion.

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